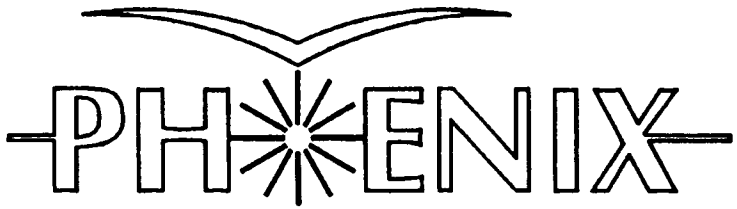

The Magnet Subsystem

Jim Thomas
Bob Yamamoto
representing the PHENIX Magnet Design Team

Lawrence Livermore National Laboratory
March 9, 1994

The PHENIX Magnet Design Team

LLNL

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Marcus Libkind
Dick Martin
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PNPI

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LANL

Walt Sondheim
Ron Barber

ORNL

Felix Obenshain
George Rennich
Tom Wright

LBL

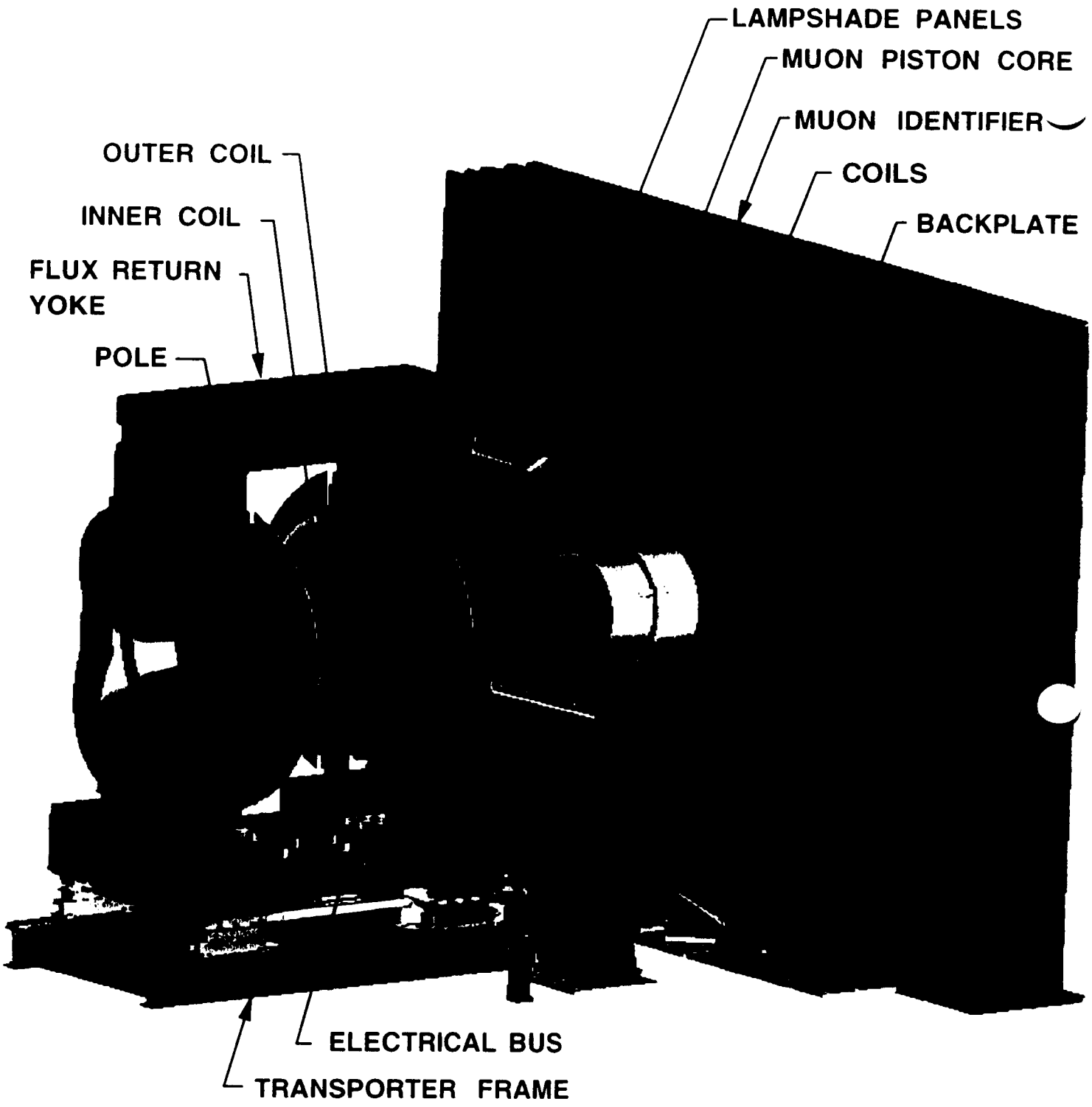
Ross Schlueter

KEK

Kazuhiro Tanaka (Banpaku)

The PHENIX Magnet Subsystem and Mu ID Steel

- PHENIX has two major magnet subsystems. The Central Magnet (CM) and the Muon Magnet (MM).
- The CM is 9 meters tall and weighs nearly 500 tons.
- The CM single particle resolution is better than 1% between 200 MeV and 1 GeV.
- One pole of the CM serves as the primary absorber of hadrons for the μ arm spectrometer. This required careful optimization of the CM pole face and the neutron and gamma ray absorbers.
- The MM is 10 meters tall and weighs more than 400 tons.
- It has sufficient resolution to resolve the Ψ' from the J/Ψ and the Υ(1S) from the Υ(2S+3S).
- The Mu ID steel is part of the muon detector but is integrated with the magnet components for design, structure, and schedule reasons.
- The Mu ID steel is 10 meters tall and weighs more than 600 tons.



PHENIX

Magnet Subsystem

The Central Magnet

- The CM is an axial field magnet energized by two pairs of concentric coils, which can be run separately, together, or in opposition.
- It covers a rapidity interval of ± 0.35 units.
- $\int B \cdot dl = 0.78$ Tesla - m
- Minimum field in the RICH region to avoid distortion of tracks $\Leftrightarrow$ rings.

  $\int B \cdot dl = 100$ gauss - m (from 2.4 to 4 meters radius)
- Minimum field at the outer radius of the CM pole where RICH phototubes will be mounted.

  $B_{Tot} \leq 200$ gauss.
- Field near the EM Cal ≤ 10 gauss.

The Muon Magnet

- The MM uses two solenoidal coils to produce a radial magnetic field. The coils are wound around a tapered piston, the flux propogates out to the lampshade and returns via a 30 cm thick endplate.
- It covers a rapidity interval of 1.1 - 2.4 units (10° to 37°).
- It has large acceptance in ϕ angle for low cross-section measurements.
- P_T kick of $\approx$ 200 MeV

  $\int B_R \bullet dl$ = 0.72 Tesla - m (along a line 15° from the beam axis).

The Mu ID Steel

- The Mu ID steel is part of the muon detector but is integrated with the magnet components for design, structure, and schedule reasons.
- The Mu ID steel and Mu ID detectors cause the hadrons to shower and still identify the straight through tracks of the muons.
- The 30 cm thick endplate for the MM is the first layer of the Mu ID absorber.
- The Mu ID absorber consists of 5 more layers of steel:
  10 cm, 10 cm, 20 cm, 20 cm, 20 cm
  each 10 m high and 10 m wide.
- It weighs over 600 tons.
- It fits. The distance between the back of the MM and the far wall is less than 3 meters!

Magnet Sub-System Status

- The Inner Coil Design is complete except for the Engineering Final Check and Drawing Check (< 1 month)
- The Outer Coil is in fabrication at Tokin Industries, Japan
- The CM Steel is in fabrication at the Efremov Institute, Russia
- The MM Coil design is complete.
- The MM Steel is in fabrication at the Efremov Institute Russia
- The Mu ID Steel is being designed, now.

The Work Plan

WBS Item	Design	Fabrication	Funding
Inner Coil	LLNL	Commercial	LLNL, PHENIX
Outer Coil	LLNL	Tokin Ind.	LLNL, PHENIX, Japan
CM Steel	LLNL et al.	Efremov Inst.	LLNL, PHENIX, Russia
MM Coil	LLNL	Commercial	LLNL, PHENIX
MM Steel	LLNL et al.	Efremov Inst.	LLNL, PHENIX, Russia
Mu ID Steel	LLNL et al.	Commercial	PHENIX

PHENIX Mag. Subsys. - Installation

- Sequence of Installation in the detector hall:
  - ancillary equipment for magnet subsystem (water lines & manifolds, electrical busing, cable trays, etc.)
  - floor plates/hardware for Mu ID Steel & MM Steel.
  - Mu ID Steel plates.
  - Muon Magnet Steel.
  - tracks (partial only) for Central Magnet.
  - Central Magnet Steel.
  - CM Outer Coil.
  - magnetic measurement hardware.
  - tracks (balance of) for Central Magnet.

  - other CM detector components as required (additional magnetic measurements if needed).

PHENIX Mag. Subsys. - CM Outer Coil Integration

- Cooling Water Interfaces:
  - water flow requirements (gpm, inlet pressure, ΔP, etc.).
  - physical interface (fitting size, location, etc).

- Electrical Interfaces:
  - power supply requirements (supply voltage required, etc).
  - physical interface (power cable attachments, quantity, etc).

- Instrumentation:
  - thermal protection (Klixons).
  - flow protection (flow switches, filtration, etc.).

- None of these items are cost or schedule "drivers".

Design Reviews – completed

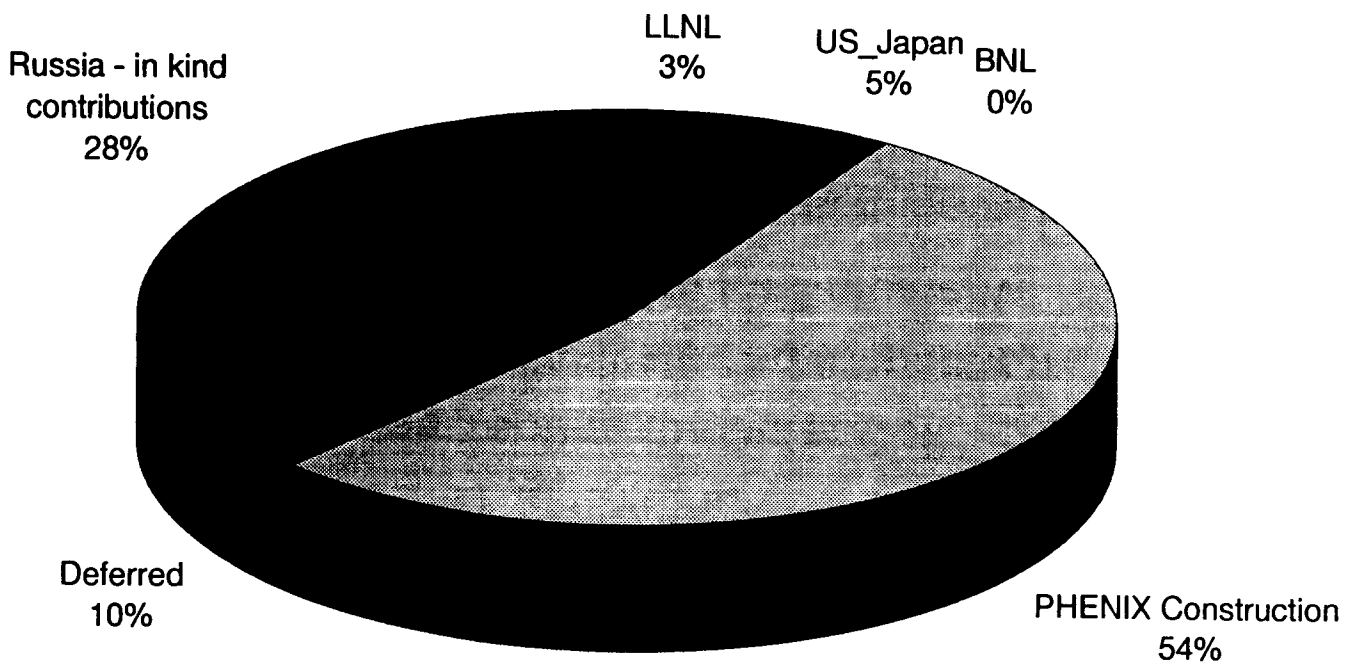
• Conceptual Magnet Design Review, Sante Fe	October 92
• Conceptual Steel Design Review, BNL	November 92
• Final Design Review for the CM outer coil	March 93
• Vendor Qualification Review at KEK (Outer Coil)	April 93
• Preliminary Design Review for the Magnet Steel	May 93
• Vendor Qualification Review at the Efremov (Steel)	June 93
• Transfer of Final Outer Coil Drawings to KEK	July 93
• Final Design Review for the Magnet Steel	August 93
• Final Design Review for the Inner CM and Muon Coils	August 93
• Conceptual MuID Design Review	October 93
• Transfer of Final Steel Drawings to the Efremov	December 93
• Review of the Magnet Steel Fabrication Plan, in Russia	February 94
• Preparation of Attachment III to the PNPI Agreement It has been signed by LLNL and PNPI.	In Progress

Upcoming Design and Fabrication Reviews

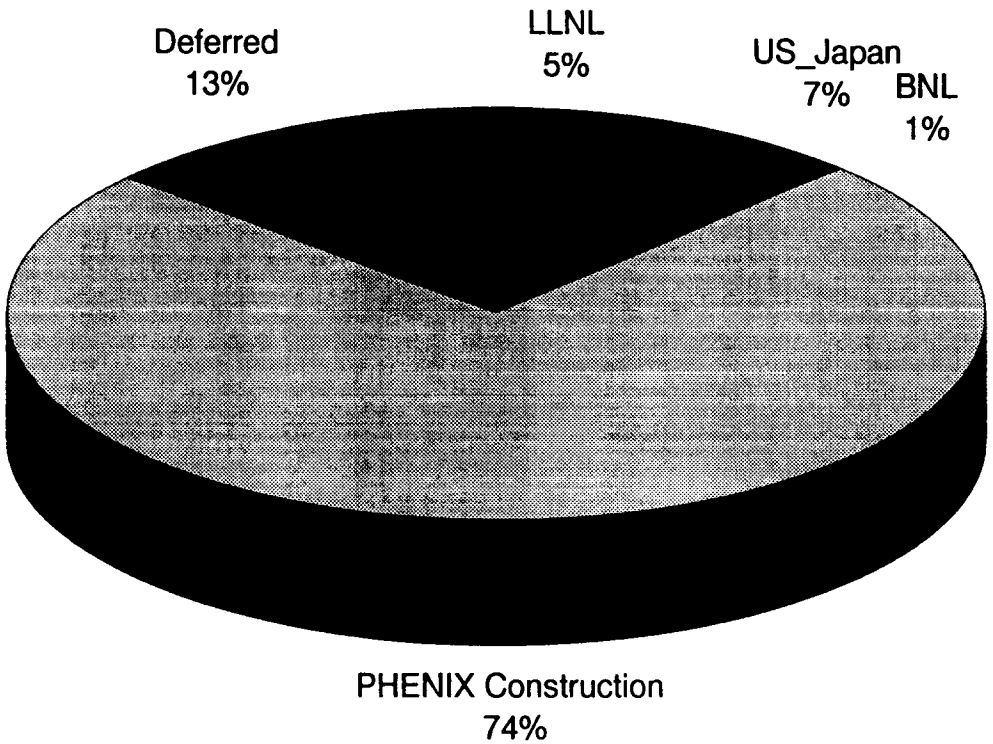
• Final Design Review for the CM Transporter	April 94
• Final Design Review for the MuID Steel	May 94
• Preliminary Review of the Rigging Plan	June 94
• Onsite Inspection of Fab Tooling for Outer Coil	June 94
• Ingot Production Chemical Analysis and Inspection	July 94
• Final Test of Outer Coil and Prepare for Shipment	October 94
• Forging and Rolled Plate Coupon & Ultrasonic Test	November 94
• Weld Inspection	February 95
• Forging Pre-machining and Ultrasonic Test	June 95
• Final Machining Dimensional Inspection & Ship	October 95
• Final Installation and Rigging Plan Review	January 96

Magnet Systems

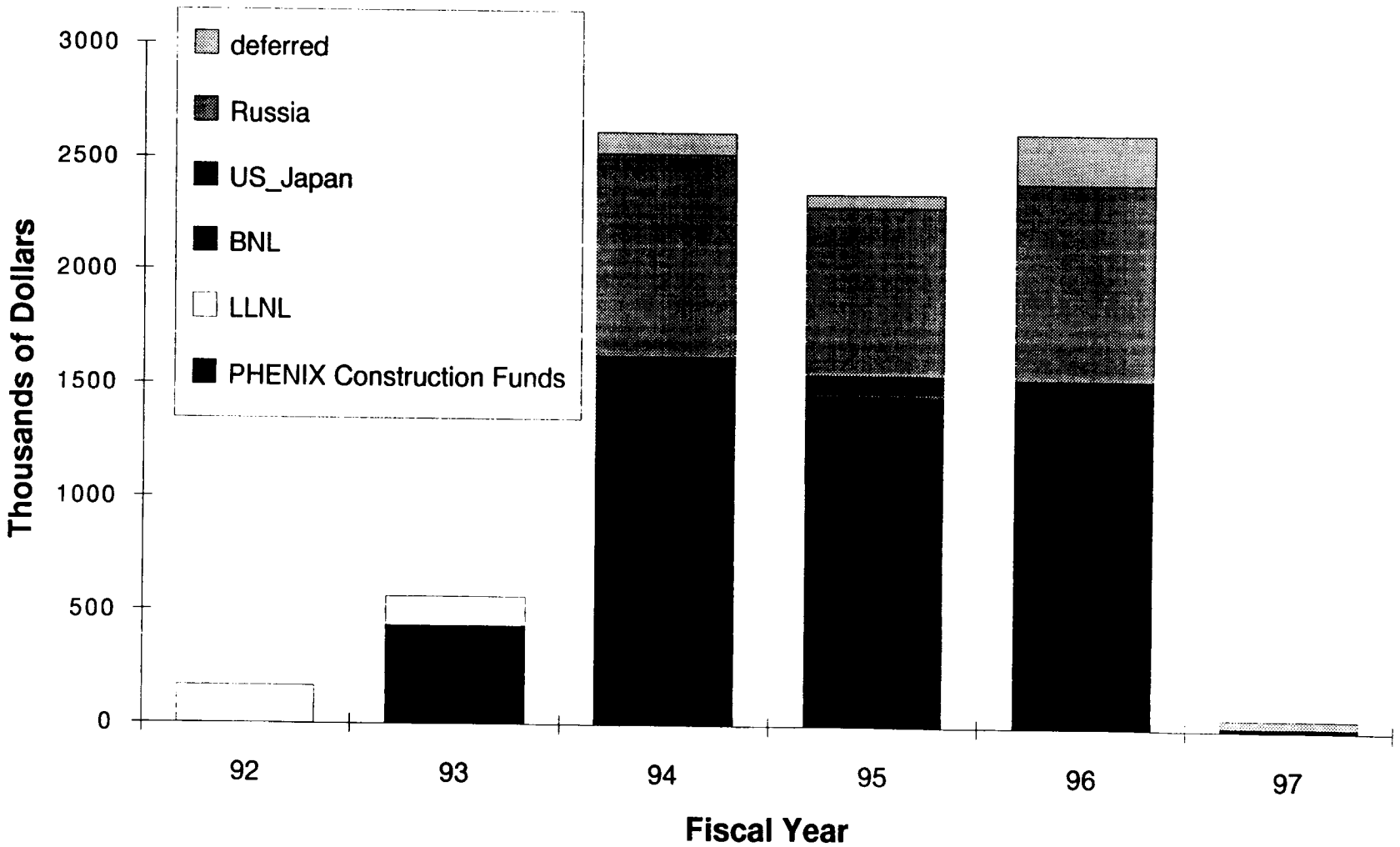
Total Cost = 8.8M



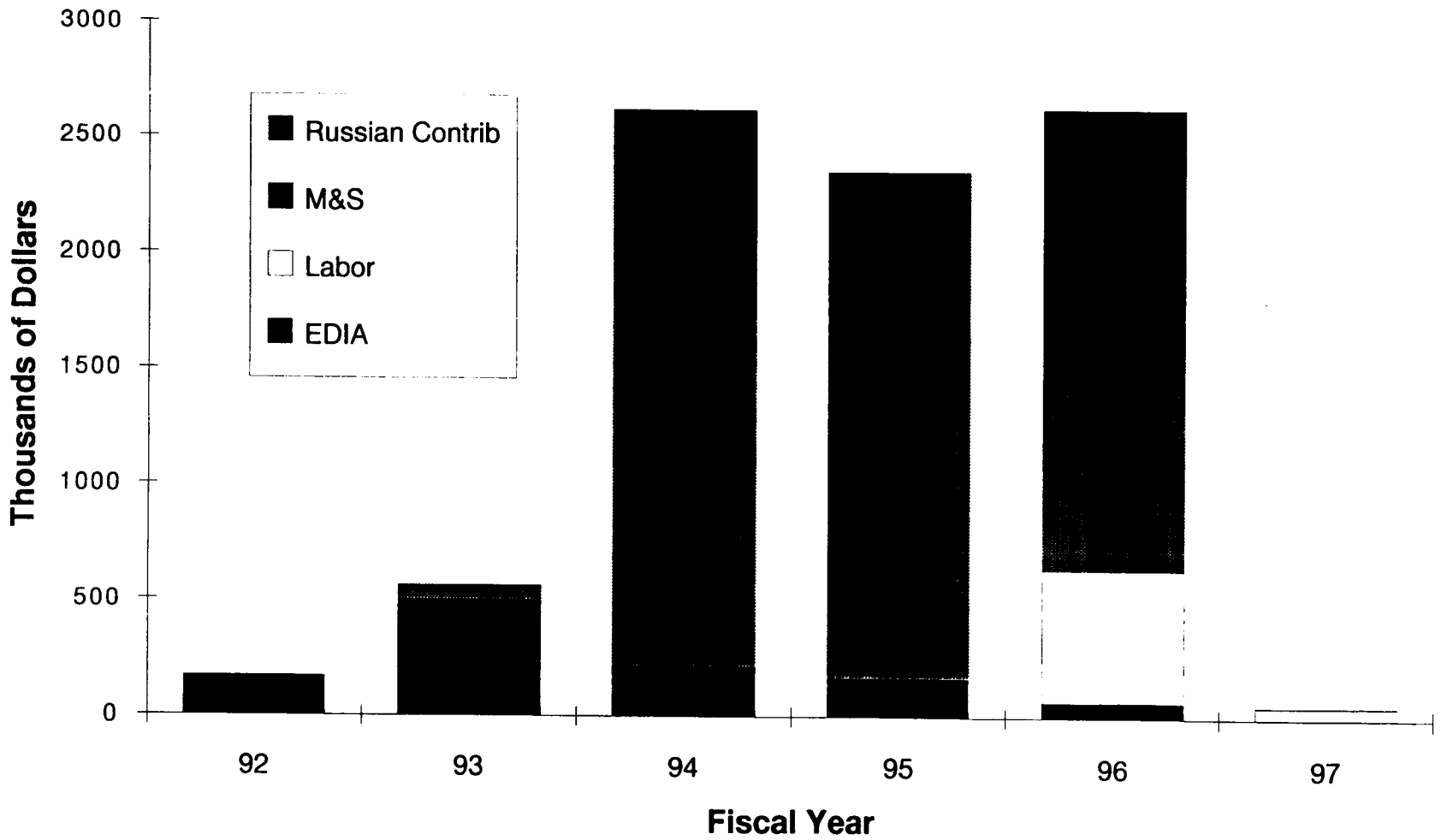
Magnet Systems Total Cost = 6.3M



PHENIX Magnet Systems Funding Profile



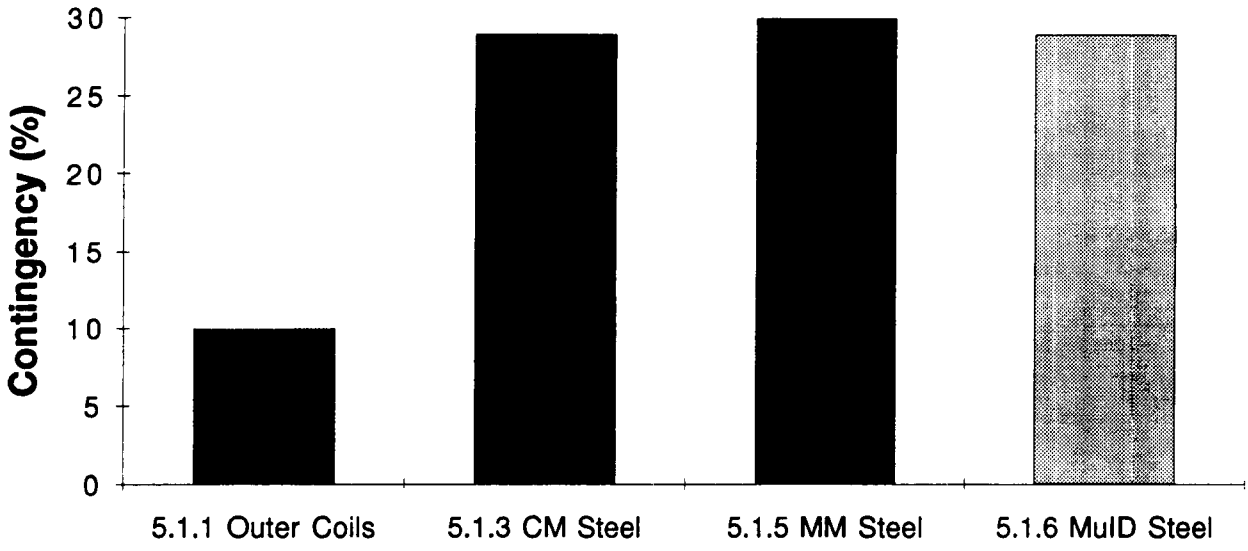
PHENIX Magnet System Funding by Category



PHENIX Mag. Subsys. - Contingency Analysis

- Contingency is calculated by multiplying a *Risk Factor* by the appropriate *Risk Percentage*.
- *Risk Percentage* is a means of measuring the type of risk involved (range is between 1% to 4%):
  - design & manufacturing as it applies to technical issues.
  - material or labor rates as it applies to cost issues.
  - schedule concerns.
- *Risk Factor* is a means of measuring just how standard or non-standard the task is (ranges between 1% to 15%):
  - technical risk (existing design or "state of the art").
  - cost risk (known cost or engineering judgment).
  - schedule risk (critical or non-critical item).
- Contingency (%) = [Technical Risk Factor x Risk Percentage] + [Cost Risk Factor x Risk Percentage] + [Schedule Risk Factor x Risk Percentage]
- For the CM Outer Coil:
  Contingency (%) = [3 x 2%] + [2 x 1%] + [2 x 1%] = 10%

PHENIX Magnet Subsystem - Contingency on Construction Dollars



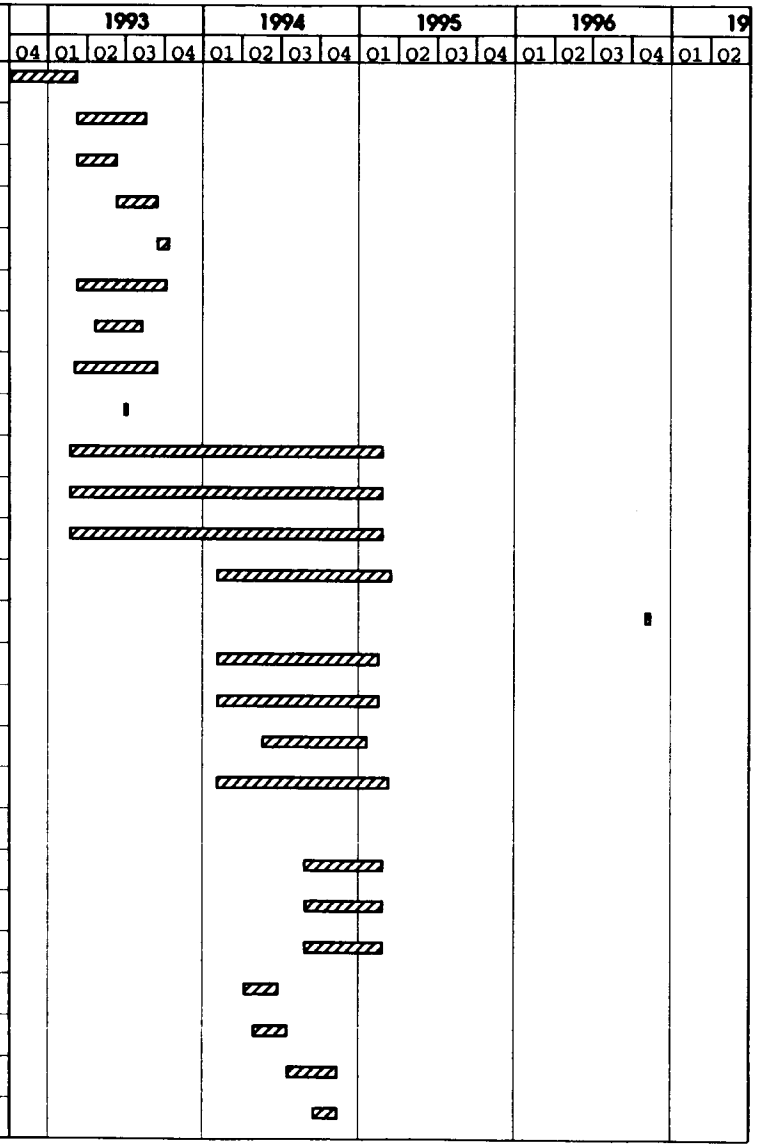
The Magnet System Schedule & Critical Path

- The Magnet System does NOT have a schedule that is defined by the critical path of the construction project. This is unusual.
- The Magnet System Schedule was driven by Opportunity
  - LLNL had $300K to put towards Engineers salaries in CY 91-93
  - The Japanese J Group had $400K to spend in Japanese FY 93
  - Large Russian in-kind contributions are available due to the collapse of the Soviet Union. Negotiations were started before the RHIC schedule slipped. The fabrication schedule was stretched 6 months to accomodate this but the fear of inflation keeps us from delaying the fabrication schedule further. The Russians would prefer a much shorter schedule.
- The MuID steel may be built in Russia. This is being negotiated, now.
- The Outer Coil, the CM Steel, the MM Steel, and the Mu ID steel are affected by these factors. Everything else is deferred.

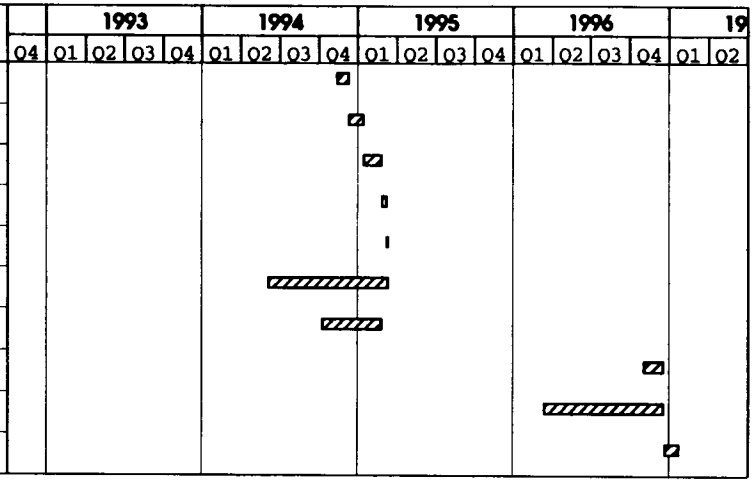
PHENIX Mag. Subsys. - Outer Coil: Critical Path

- Finalize coil specifications.
- Design/detail drawings.
- Vendor bid cycle (from KEK).
- Award contract to Japanese Industry.
- Conductor fabrication.
- Coil winding tooling & coil winding.
- Coil potting tooling & coil potting.
- Coil testing.
- Ship coil to BNL.
- Install coil onto CM poles.
- Magnetic mapping of Central Magnet.

WBS	Description	Total Cost
2.1.1.1.1	Preconceptual Engineering Design	$72,410.00
2.1.1.1.1	Magnetic Analysis	$4,640.25
2.1.1.1.1	Preliminary Design	$13,011.00
2.1.1.1.1	Detail Design	$19,516.50
2.1.1.1.1	Drawing Check	$3,252.75
2.1.1.1.1	Engineering Analysis	$22,582.55
2.1.1.1.1	Thermal Analysis	$9,899.20
2.1.1.1.1	Project Mgmt/Engr	$10,818.65
2.1.1.1.2	Japan Trip (design)	$4,000.00
2.1.1.1.3	TID services	$588.00
2.1.1.1.4	Computer support	$2,604.00
2.1.1.1.5	FedEx	$1,302.00
2.1.1.1.7	Engineering Interface, Inspection	$18,561.00
2.1.1.1.7	Final Engineering Inspection	$4,640.25
2.1.1.1.7	Fabrication and design support	$13,011.00
2.1.1.1.7	Procurement Specialist	$6,505.50
2.1.1.1.8	Japan Trip (fab)	$7,994.00
2.1.1.1.9	Domestic Trip (fab)	$8,002.80
2.1.1.2	CM Outer Coil Prototype	$0.00
2.1.1.3.1	Fixtures	$30,004.24
2.1.1.3.1	Water Manifolds	$19,999.20
2.1.1.3.1	Support Hardware	$7,996.24
2.1.1.3.1	Conductor Fabrication	$60,000.64
2.1.1.3.1	Winding Tooling	$24,998.40
2.1.1.3.1	Coil Winding	$100,000.80
2.1.1.3.1	Potting Mold	$40,000.80



WBS	Description	Total Cost
2.1.1.3.1	Coil Vacuum Potting	$150,000.00
2.1.1.3.1	Coil Testing	$25,000.00
2.1.1.3.1	coil transportation to US (Japan	$70,000.80
2.1.1.3.1	US Customs	$0.00
2.1.1.3.1	Transportation from Port of Entry	$10,000.08
2.1.1.3.2	power supplies	$97,248.00
2.1.1.4.1	Prepare Fixturing	$3,040.00
2.1.1.4.5	Assembly Labor	$24,890.00
2.1.1.5.1	Magnetic mapper(50%)	$50,000.00
2.1.1.5.2	Mapping labor	$20,136.21



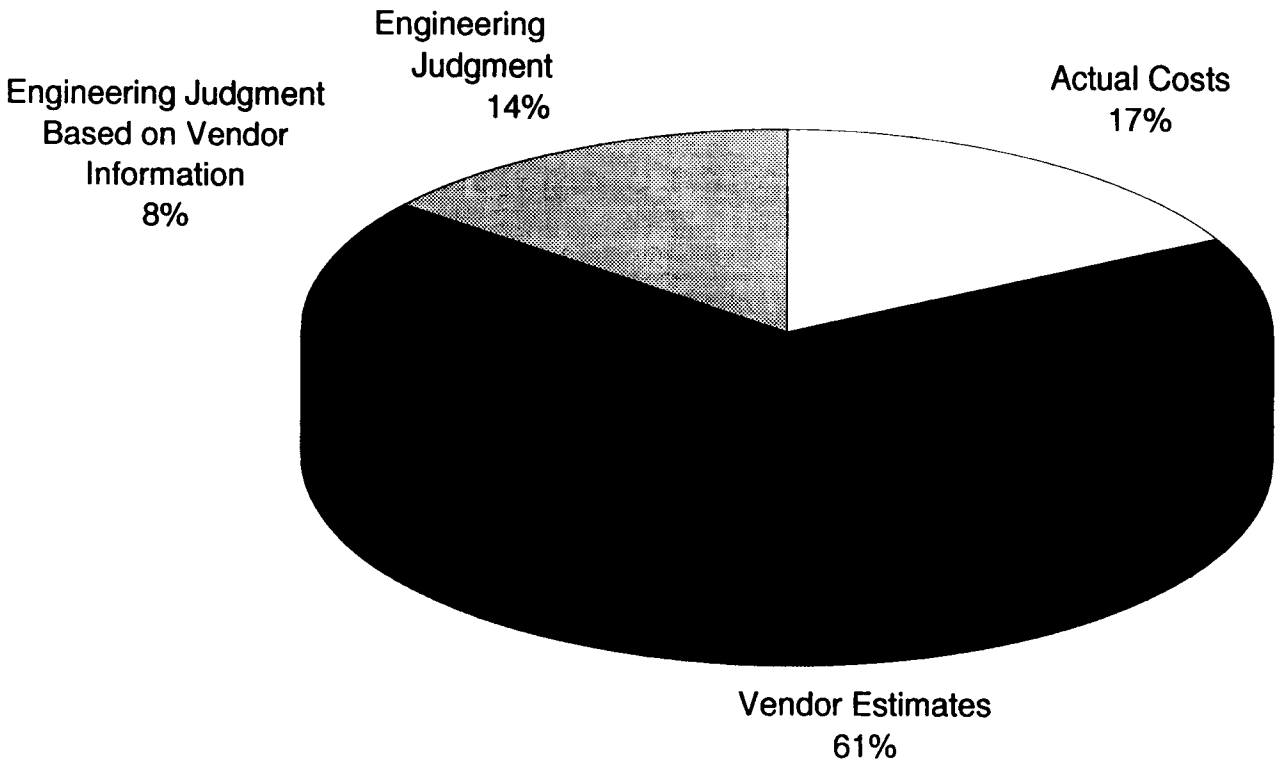
PHENIX Mag. Sys. - CM Outer Coil Milestones

Date	Title
April, 1993	Visit to Japan: KEK + coil fabricator.
May, 1993	Detailed Outer Coil Dwgs. complete - sent to KEK.
July, 1993	Coil package "out for bid" in Japan.
October, 1993	Coil contract awarded to TOKIN Corp.
December, 1993	Start fabrication of copper conductor (Hitachi).
June, 1994	Validate coil fab. tooling (potting molds, etc).
October, 1994	Validate coil testing (hydraulic, electrical, etc.).
November, 1994	Coil complete - ship to BNL.
August 1996	Installation of coil onto CM poles.
November 1996	Mapping of Central Magnet.

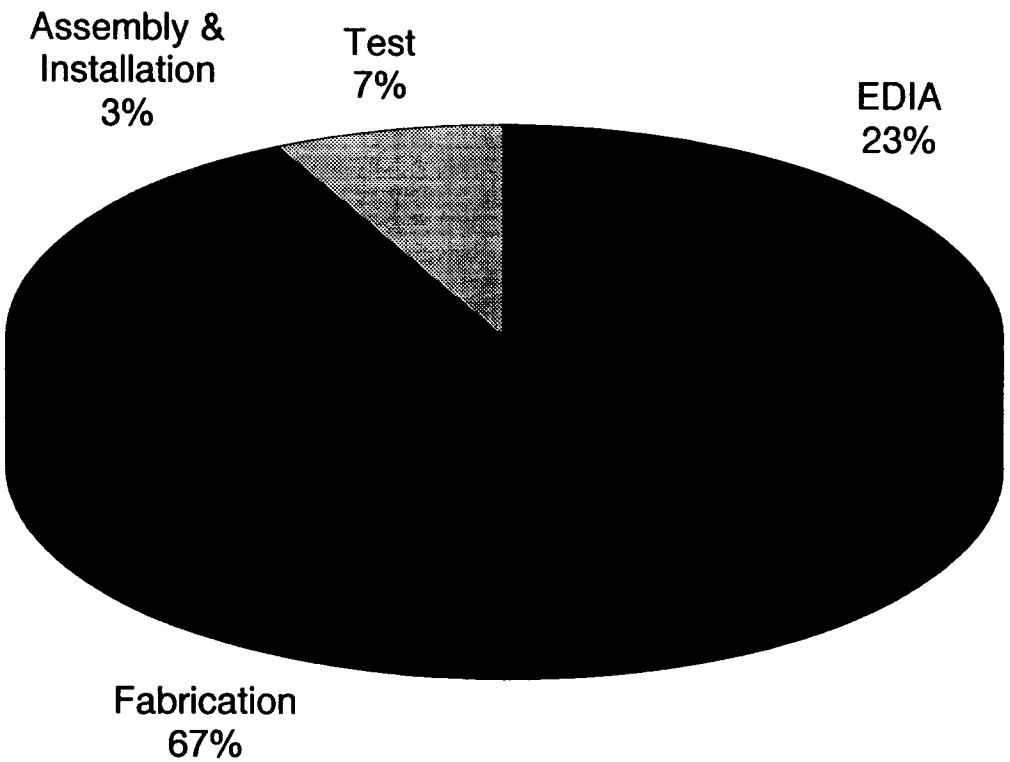
PHENIX Mag. Subsys. - Outer Coil: Basis of Est.

- EDIA estimated using comparative data from "like" task:
  - design EDIA complete.
  - fabrication EDIA approx. 10% complete & "on budget".
- Fabrication estimate based on solid vendor estimates:
  - coil to be supplied by KEK/Japanese industry.
  - power supply to be supplied by US industry.
- Assembly, Installation and Testing based on engineering judgment of "like" tasks:
  - comprises only 14% of total coil cost.
- CM Outer Coil is a non-critical item:
  - total contingency only 10%.

CM Outer Coil - Type of Estimate

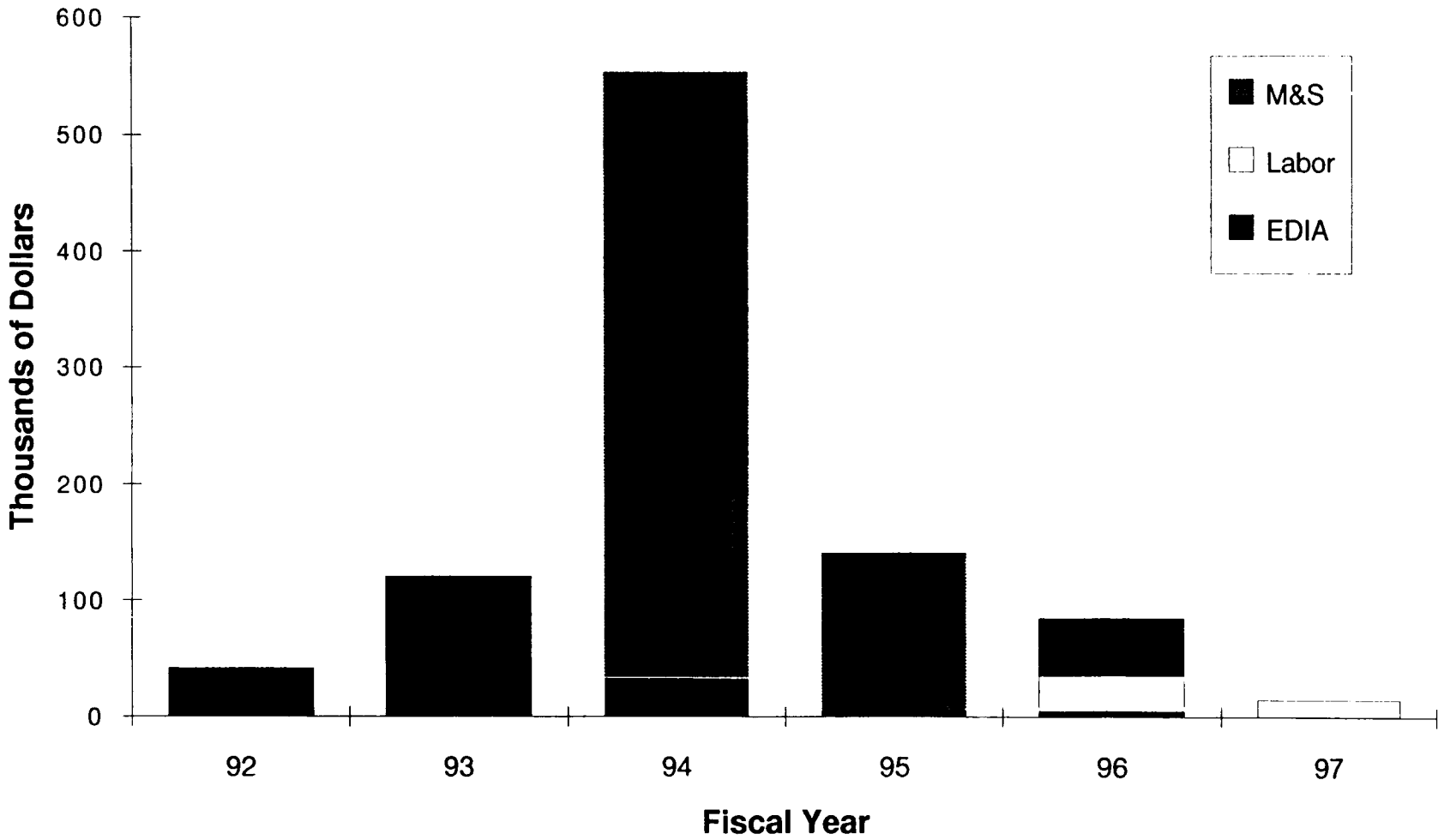


PHENIX Magnet Outer Coil - Level 4 Summary

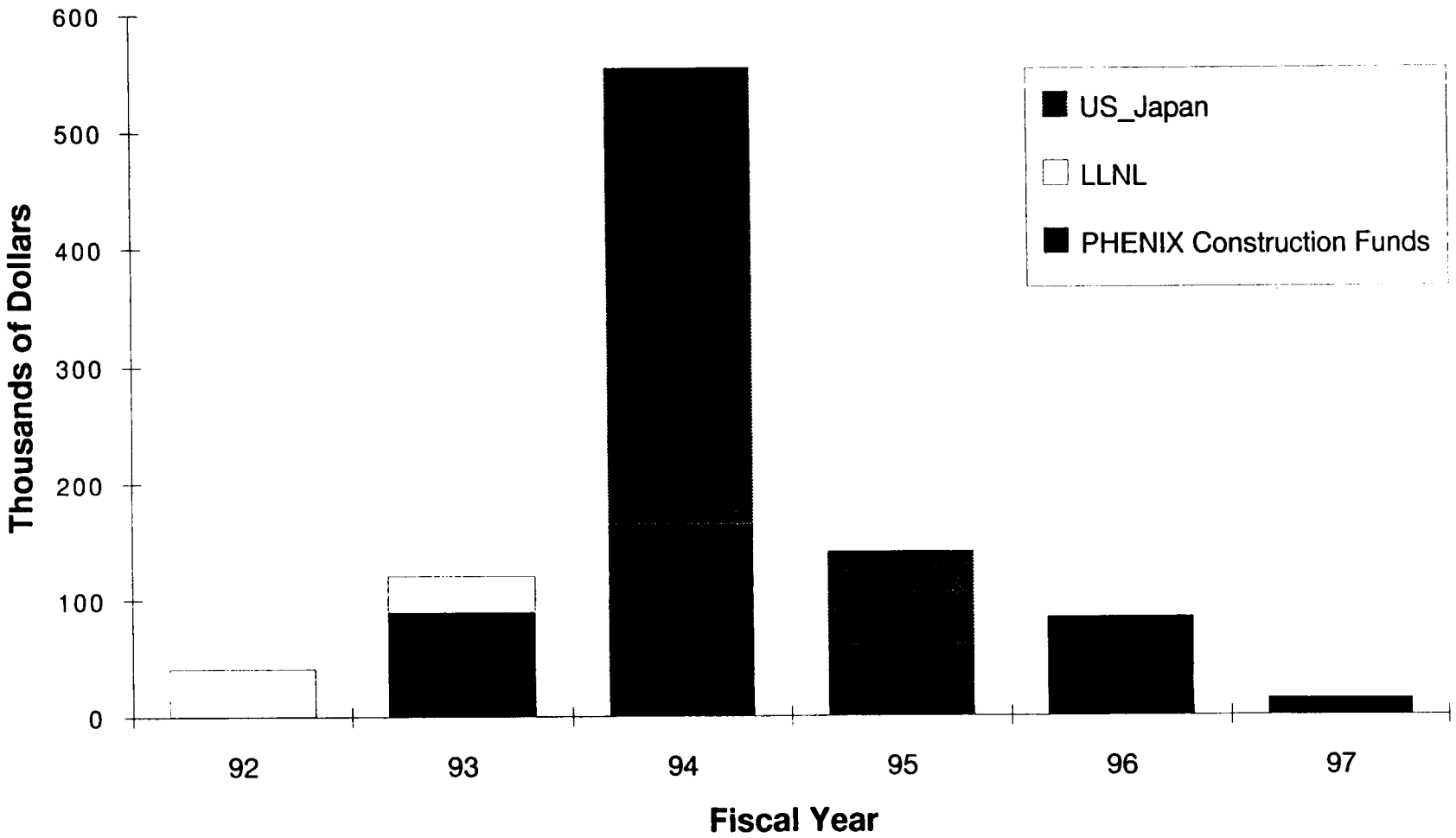


Total Outer Coil Cost: $956K

Outer Coil Funding Profile by Category



Outer Coil Funding Profile by Source



PHENIX Mag. Subsys. - Schedule Validation

- Discussions will include schedule validation for the:
  - CM Outer Coil presently being fabricated in Japan.
  - CM & MM Steel presently being fabricated in Russia.

- CM Outer Coil validation topics:
  - coil brazing tests.
  - electrical joint gasket tests.

- CM & MM Steel validation topics:
  - site visit to Russia (Feb '94)
  - milestones 4.1.0 & 4.1.1 complete.

PHENIX Mag. Sys. - Dsgn Reviews & Site Visits

Date	Title
October, 1992	PHENIX Collaboration Meeting; Santa Fe, NM.
November, 1992	Coil Analysis Review; Steel Design Update.
February, 1993	TAC Review.
March, 1993	FDR: Central Magnet Outer Coils.
April, 1993	Visit to Japan: KEK + Coil Fabricator.
May, 1993	PDR: Central Magnet & Muon Magnet Steel.
June, 1993	Visit to Russia: Efremov/PNPI/Izhora Steel/LMZ.
August, 1993	FDR: Muon Magnet Coil.
August, 1993	FDR: Central Magnet & Muon Magnet Steel.
November, 1993	TAC Technical, Cost & Schedule Review.
February, 1994	Visit to Efremov: Review CM & MM Steel drwgs.

PHENIX Mag. Subsys. - Coil Brazing Tests

- Per the LLNL CM Outer Coil Specification, TOKIN Corp. has prepared 12 brazing samples using the actual copper conductor to be used for the CM Outer Coil. The braze samples joined 2 pieces of conductor together using a sleeve coupling at the butt joint.

- 6 braze samples used a copper phosphorus braze material (Handy Harmon Sil-Fos 5).

- 6 braze samples used a silver braze material (Handy Harmon Braze 560).

PHENIX Mag. Subsys. - Coil Brazing Tests

- Tests were conducted at LLNL and included the following:

- Hydrostatic Leak Test:
  - each test sample was tested at pressure intervals of 75, 100 and 150 PSIG for a period of 5 minutes each.
  - no detectable leaks or sign of material deformation in any sample.

- Vacuum Leak Test:
  - each test sample was vacuum leak tested (detector sensitivity: 3.7×10^{-10} atmosphere cc/sec/div.)
  - no detectable leaks in any sample.

PHENIX Mag. Subsys. - Coil Brazing Tests

- Tensile Test:
  - 3 copper phosphorus braze samples and 3 silver braze samples were tested.
  - all test samples failed at a load equating to a tensile strength of approx. 28.5 KSI. This is in the range of published data for annealed copper.

- Section Test:
  - 1 copper phosphorus braze tensile test sample and 1 silver braze tensile test sample was sectioned.
  - the sectioned samples show good braze adhesion and flow characteristics.

- Conclusion:
  - either braze material can be used.
  - braze technique has been satisfactorily validated.

PHENIX Mag. Subsys. - Electrical Joint Tests

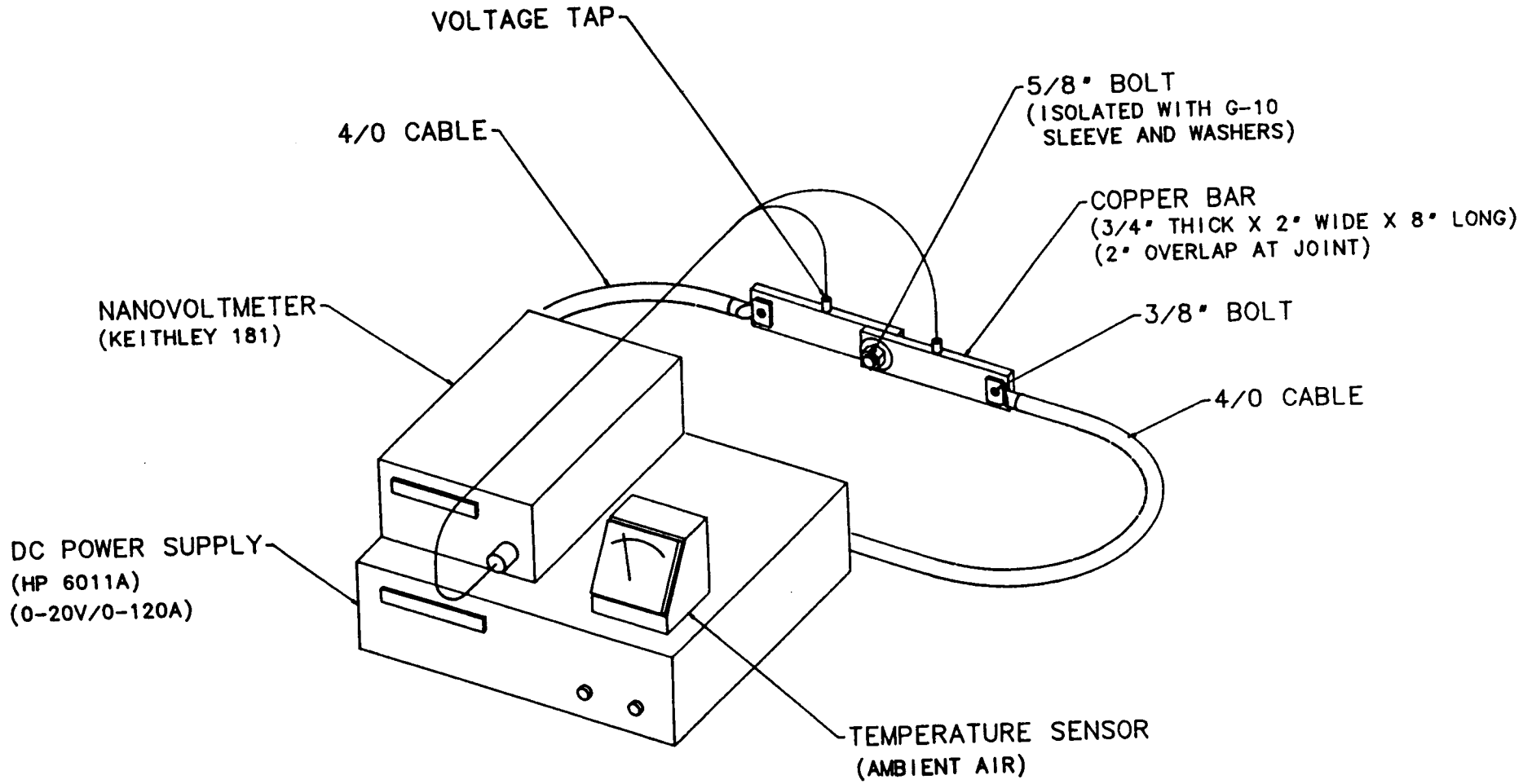
- Purpose of tests:
  - To verify that the "FoamMetal" (sintered copper material) is better at carrying electrical current between a coil terminal flag and power bus than traditional methods.

- Materials tested:
  - "FoamMetal" unplated.
  - "FoamMetal" silver plated.
  - fine copper screen unplated.
  - fine copper screen silver plated.
  - coarse copper screen unplated.
  - bus bars silver plated.
  - thin copper sheet unplated.
  - silver plated screen sandwiched between 2 silver plated copper sheets.
  - silver plated "FoamMetal" + silver plated screen.
  - silver plated screen + silver plated "FoamMetal" + wedge.

PHENIX Mag. Subsys. - Electrical Joint Tests

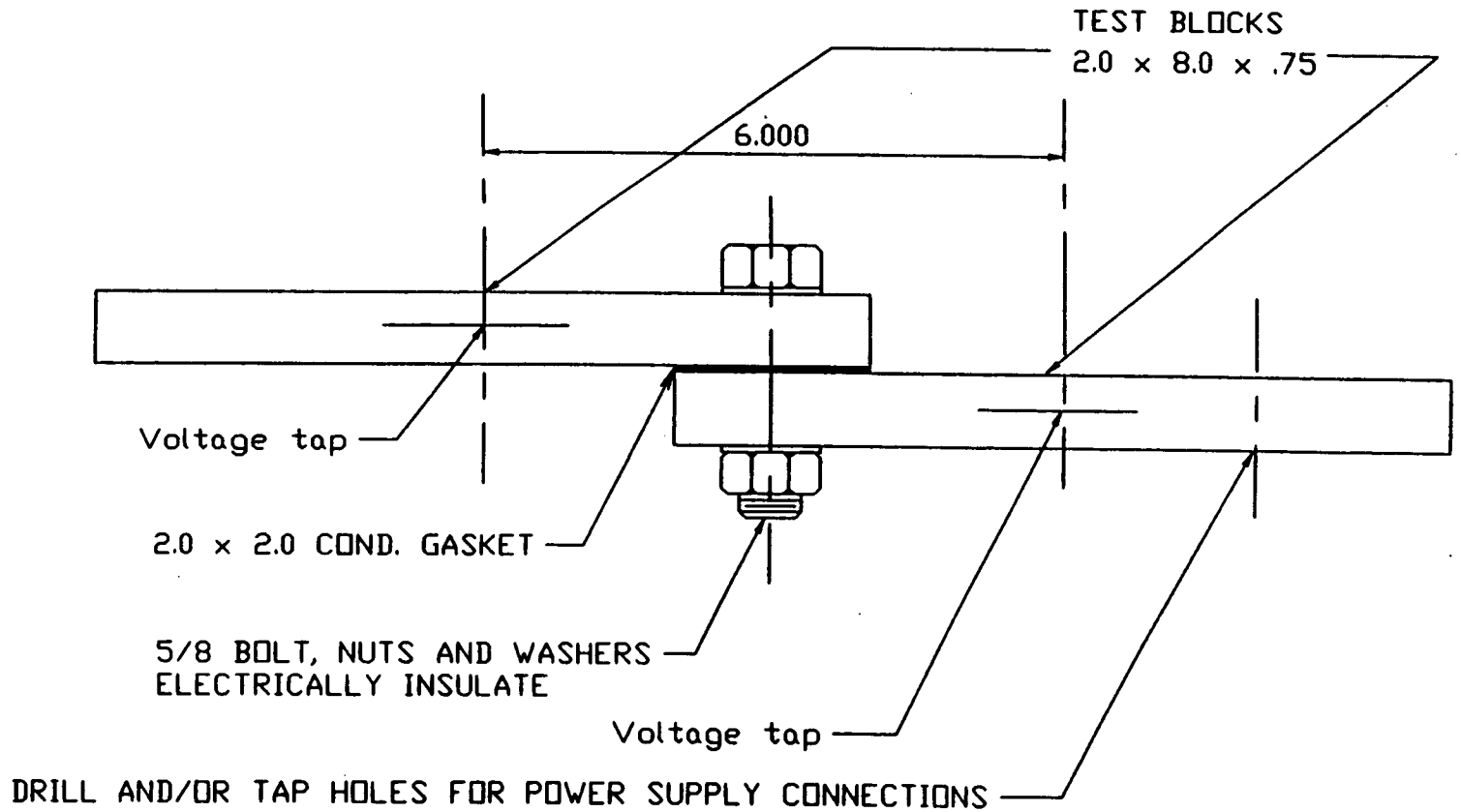
- Test parameters:
  - measure voltage drop across samples.
  - current ranged from 20 to 100 amps in 10 amp increments (brought up from lower value to peak and retraced down to lower value).
  - torque settings ranged from 20 to 60 ft-lbs in 10 ft-lb increments and then reduced to 30 ft-lbs in 10 ft-lb increments.

PHENIX Mag. Subsys. - Elect. Joint Test Set-up

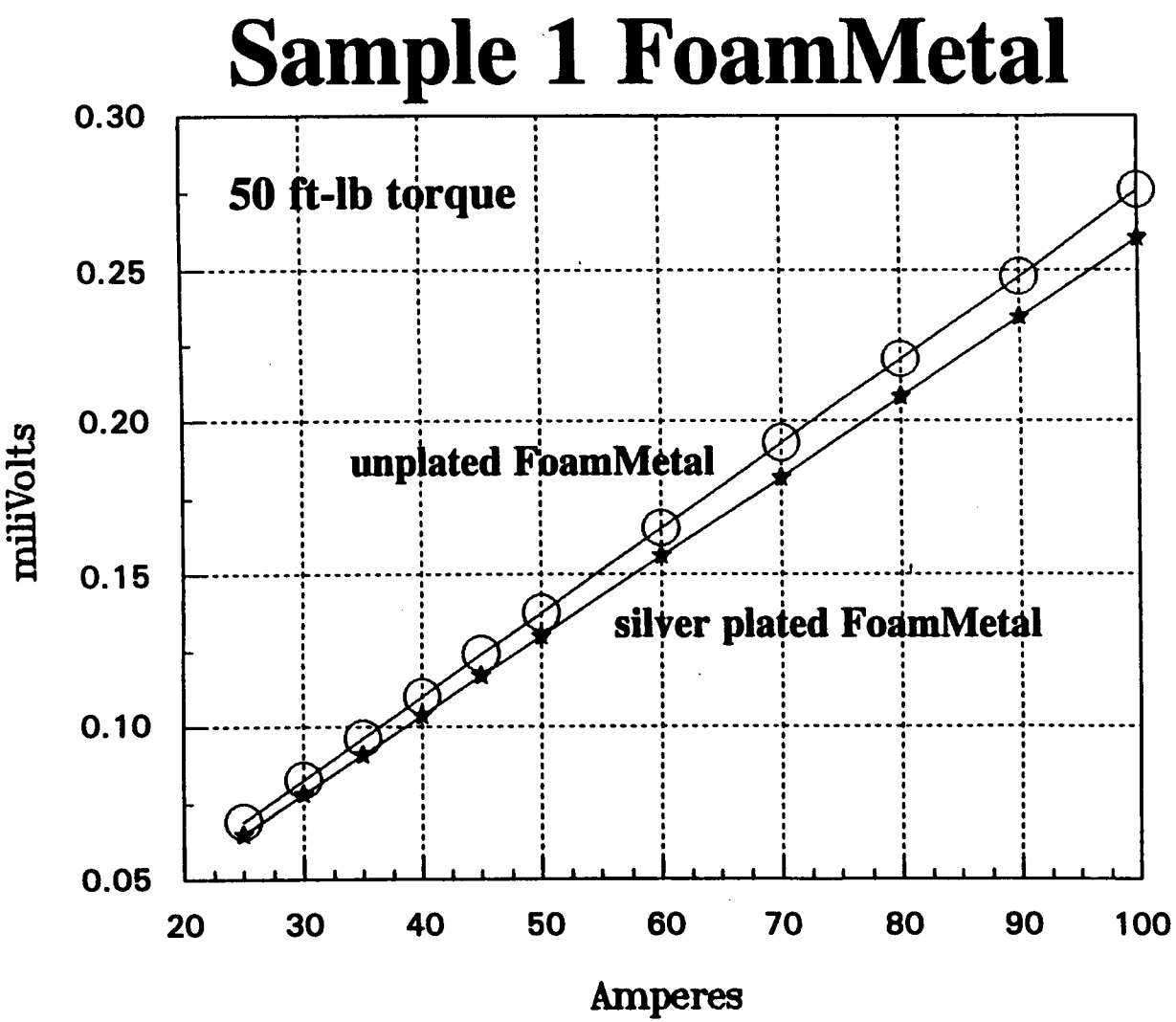


RMY-01
3/5/94

PHENIX Mag. Subsys. - Test Bus Assmebly



PHENIX Mag. Subsys. - "FoamMetal" Test Data



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3/5/94

PHENIX Mag. Subsys. - Electrical Joint Tests

- Conclusions:
  - "FoamMetal" is more conductive than bare contact, sheet or screen at comparable test settings.
  - "FoamMetal" has sufficient elasticity to adequately recover conductivity with little loss at a reduction in torque.
  - "FoamMetal" conductivity is least affected by torque settings for all materials tested.
  - "FoamMetal" conducts well between two mating unparallel surfaces (non-uniform gasket pressure).

  - silver plated samples are more conductive than unplated samples for all materials tested.

Focus of design efforts since fall '93 review

- Completion of detail drawings for muon and central magnet
- Final negotiations with Russians on specifications
- Design of track system for the mobile CM
- Completion of rigging study RFP

JMB
3/4/94

Current status of magnet steel effort

- Detail drawings have been shipped to Russia
- Attachment 3 has been signed with Efremov and PNPI
- Rigging study contract awarded to Bigge Crane and Rigging
- Track/transporter drawings in checking

Detail drawings

- Efremov has translated LLNL drawings to Russian standards
- We have reviewed Russian drawings and approved them
- Many technical negotiations in Russia
- RESULTS:

Spirit of cooperation between Efremov and LLNL

High level of LLNL confidence in Efremov

Efremov is part of the design team, not just a supplier

Attachment 3

- Efremov has translated Attachment 3 to Russian standards
- We have resolved spec. issues with the Izhora steel mill
- We met directly with Izhora upper management
- RESULTS:

Director of the largest steel mill in Russia has personally guaranteed the success of this project

Efremov and Izhora are cooperating on fabrication details

Summary of recent visit

- Intense, productive interaction with Efremov design team
- Detailed review of facilities at the Izhora Works
- Clear mutual understanding of expectations
- Precedent for future interaction and site visits
- Access to highest levels of Efremov, PNPI & Izhora management
- Because of cultural, language, and style differences, face to face is the only means control the project.

JMB
3/4/94

Russian labor in Russia

Items included on steel purchase order:

- **Steel production**
- **Analysis and material testing**
- **Preparation of test reports (CMTR's, UT, etc)**
- **Maintenance of PHENIX fabrication quality assurance records**
- **Fabrication and machining**
- **In house ultrasonic testing, dimensional and weld**
- **Assembly and off site rigging**
- **Packaging for shipment**
- **Transfer and loading to ocean carrier**

U.S. labor in Russia

- Witness steel production chemical analysis
- Witness mechanical, magnetic, and chemical coupon testing
- Audit welding QA records
- Witness ultrasonic inspection
- Perform dimensional inspection on parts
- Perform weld inspection
- Witness assembly
- Perform dimensional inspection on assembly
- Witness packaging for shipment

JMB
3/4/94

Accountability of Russian procurements

- LLNL detailed fabrication specification
- Specific milestone payments included in specification
- LLNL will make 6 site visits during contruction

PHENIX Mag. Sys. - Russian Compensation Schd.

Milestone	Description	Payment
4.1.0	*Purchase of steel (completed)*	*$400,000*
4.1.1	*Preliminary documentation (completed)*	*32,000*
4.1.2	Progress documentation	32,000
4.1.3	Ingot Production, ladle chemical analysis/magnetic analysis	32,000
4.1.4	Plate Rolling Production, coupon testing	32,000
4.1.5	Rolled plate cutting/premachining/ultrasonic testing	32,000
4.1.6	Forging Production, heat treatment, coupon testing	32,000
4.1.7	Weldment production, weld inspection	32,000
4.1.8	Forging premachining/ultrasonic testing	32,000
4.1.9	Final machining, dimensional inspection	240,000
4.1.10	Off site assembly, dimensional inspection	320,000
4.1.11	Packaging/crating	64,000
4.1.12	Shipping to US port of entry	320,000
	Total:	$1,600,000

RMY-01
3/3/94

PHENIX Mag. Subsys. - Coil Cooling Water

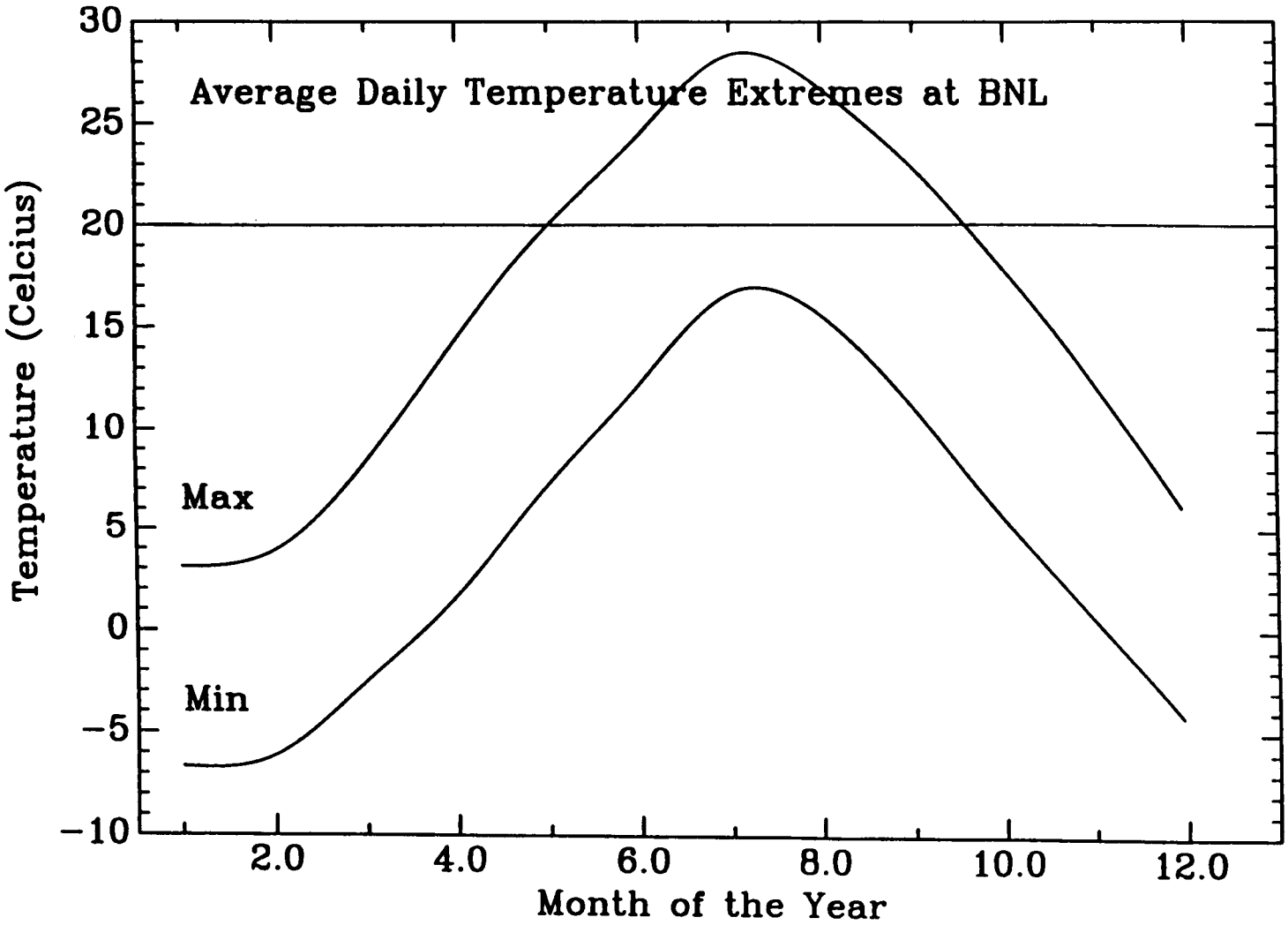
- At the last TAC Review (Nov. '93) the committee was concerned about the effect of the decision to defer the chiller system for low conductivity water for the magnet subsystem. Further understanding was requested by the committee on the consequences of this decision with regards to higher coil operating temperatures which translate into increased power consumption and increased voltage drop and the affects on the operation of other detector components.

PHENIX Mag. Subsys. - Coil Cooling Water

- Analysis completed using an inlet water temperature of 30°C (vs. baseline design of 20°C).
  - this number based on temperature data supplied by Pete Kroon on the average yearly temperatures at BNL.

- Analysis done for the CM Outer Coil only:
  - only coil presently being constructed.
  - operates at the highest average coil temperature (32.8°C).
  - has the most copper in it (most power consumption, 300 Kw).
  - is the worst case coil scenario.

PHENIX Mag. Subsys. - Avg. Temperatures @ BNL



PHENIX Mag. Subsys. - Coil Cooling Water

- Results:
  - average coil operating temperature increased from 32.8°C to 43.3°C (10.5°C change).
  - coil operating voltage increased from 173.5 volts to 180.4 volts (6.9 volt change). For comparison, power supply cable (8 - 500 MCM cables) voltage drop is 86 volts per 1000 ft of cable length.
  - coil power consumption increased from 298 kwatts to 310 kwatts (12 kwatt change). The power supply (one only to supply 2 coils in series) is rated at 1000 kwatts (620 kwatts required at an inlet water temperature of 30°C).